In Situ Measurement of Rock Viscosities by Sakata-type Three-component Strainmeters

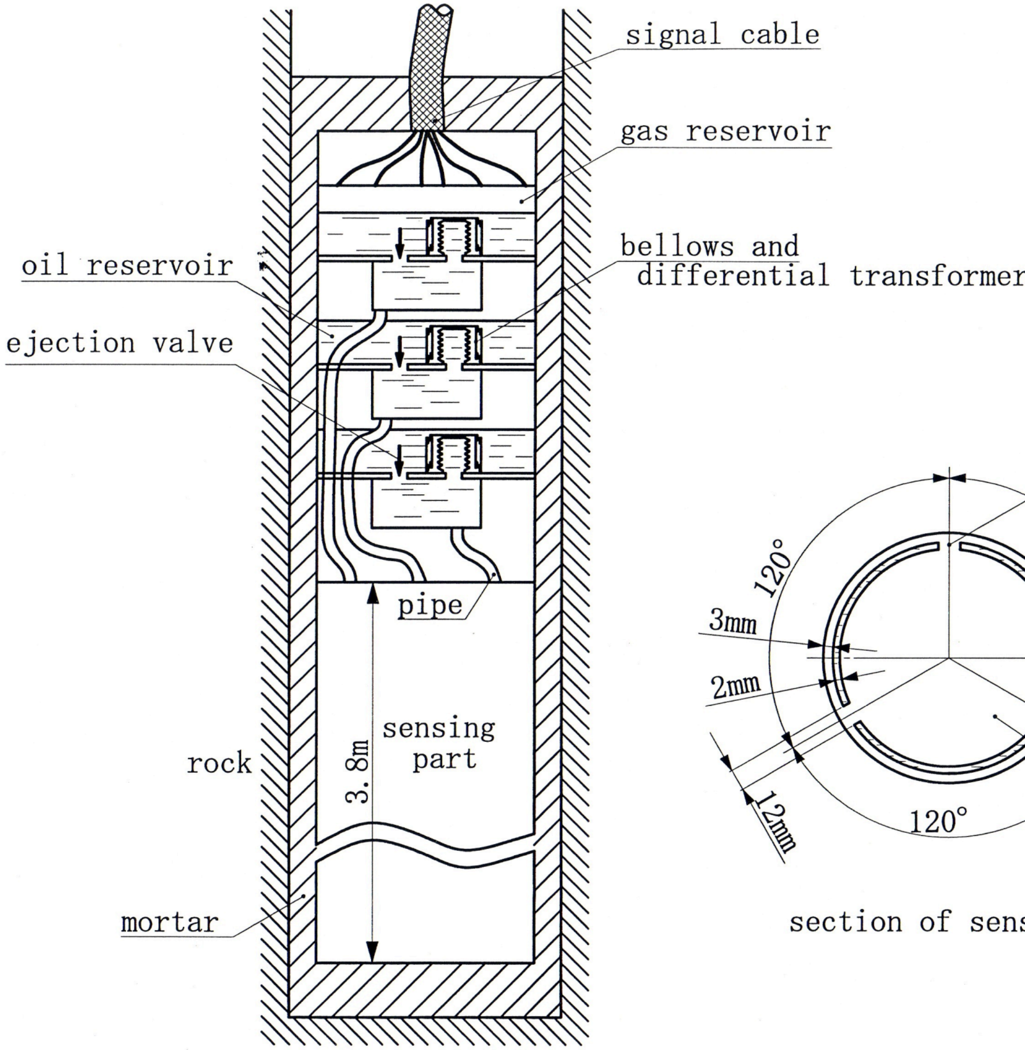
Shoji SAKATA

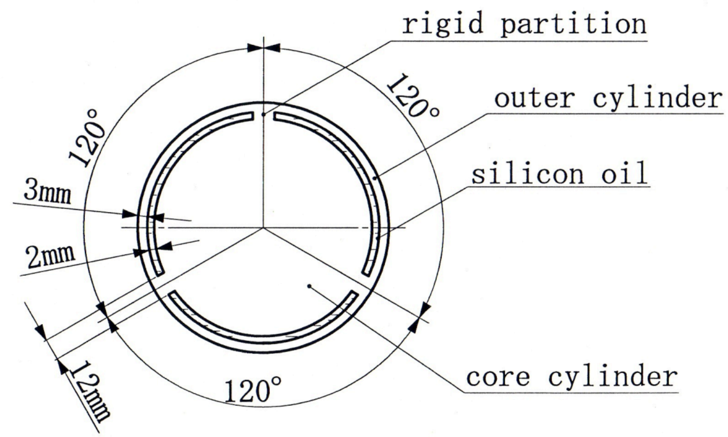
(NIED)

Contents

1. Viscosities of surface rocks were obtained by analyzing long-term continuous records of Sakata-type three-component strainmeters.

2. Viscosity could play an important role in stress accumulation process in the crust.



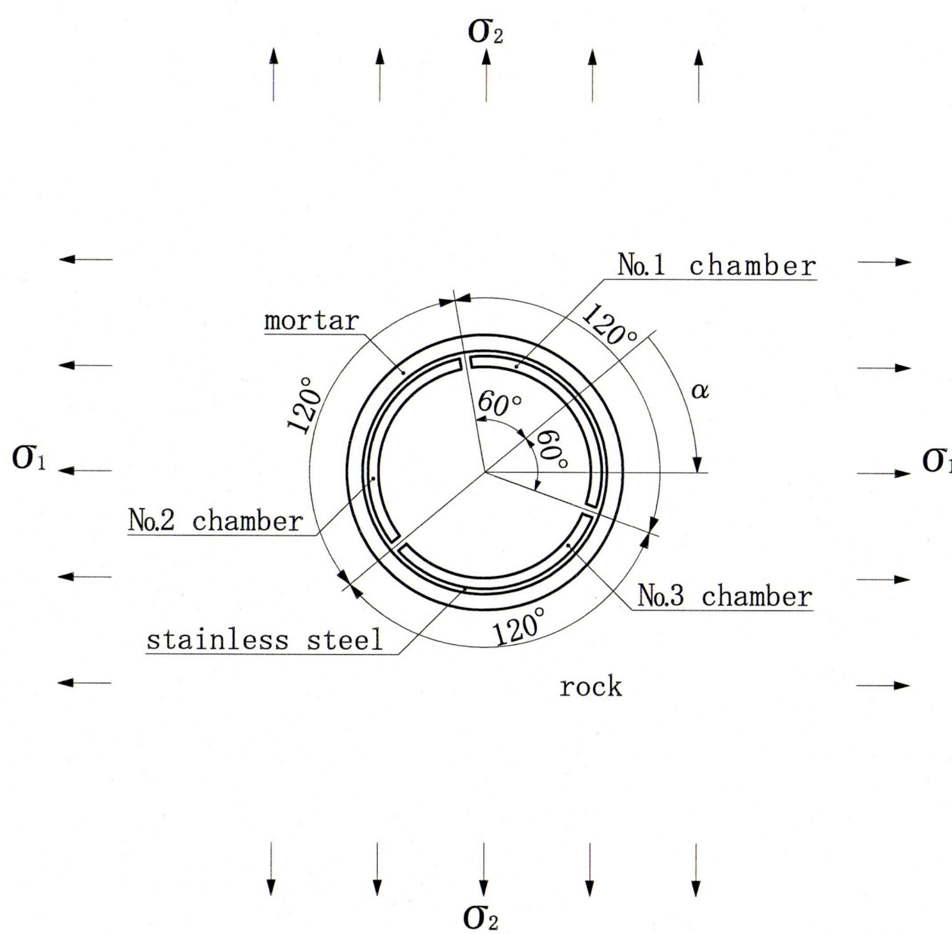


section of sensing part

Schematic drawing of Sakata-type three-component strainmeter

Cut model of the sensing part of Sakata-type three-component strainmeter

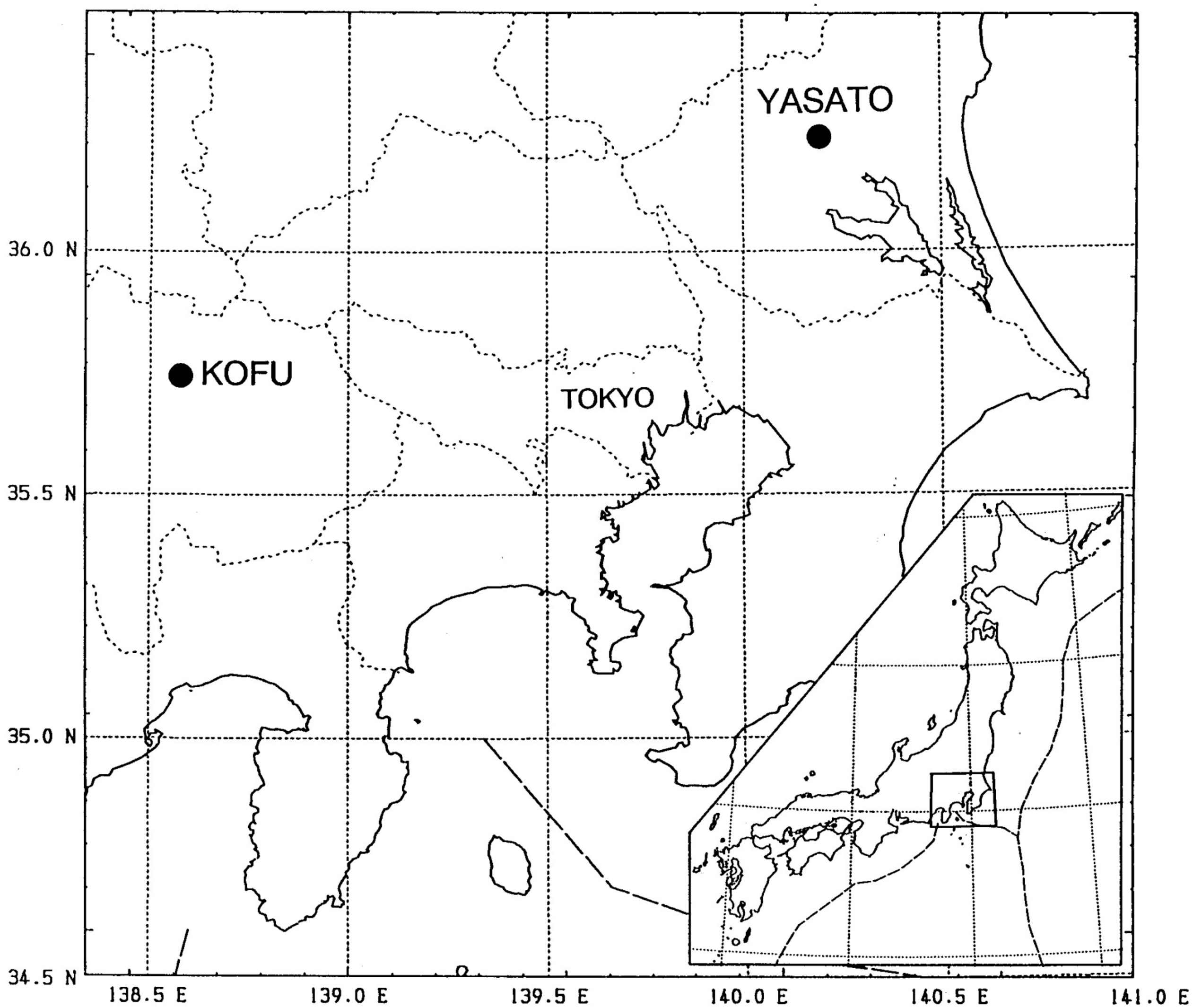
Outer diameter : 114mm, thickness of the outer plate : 3mm, clearance : 2mm



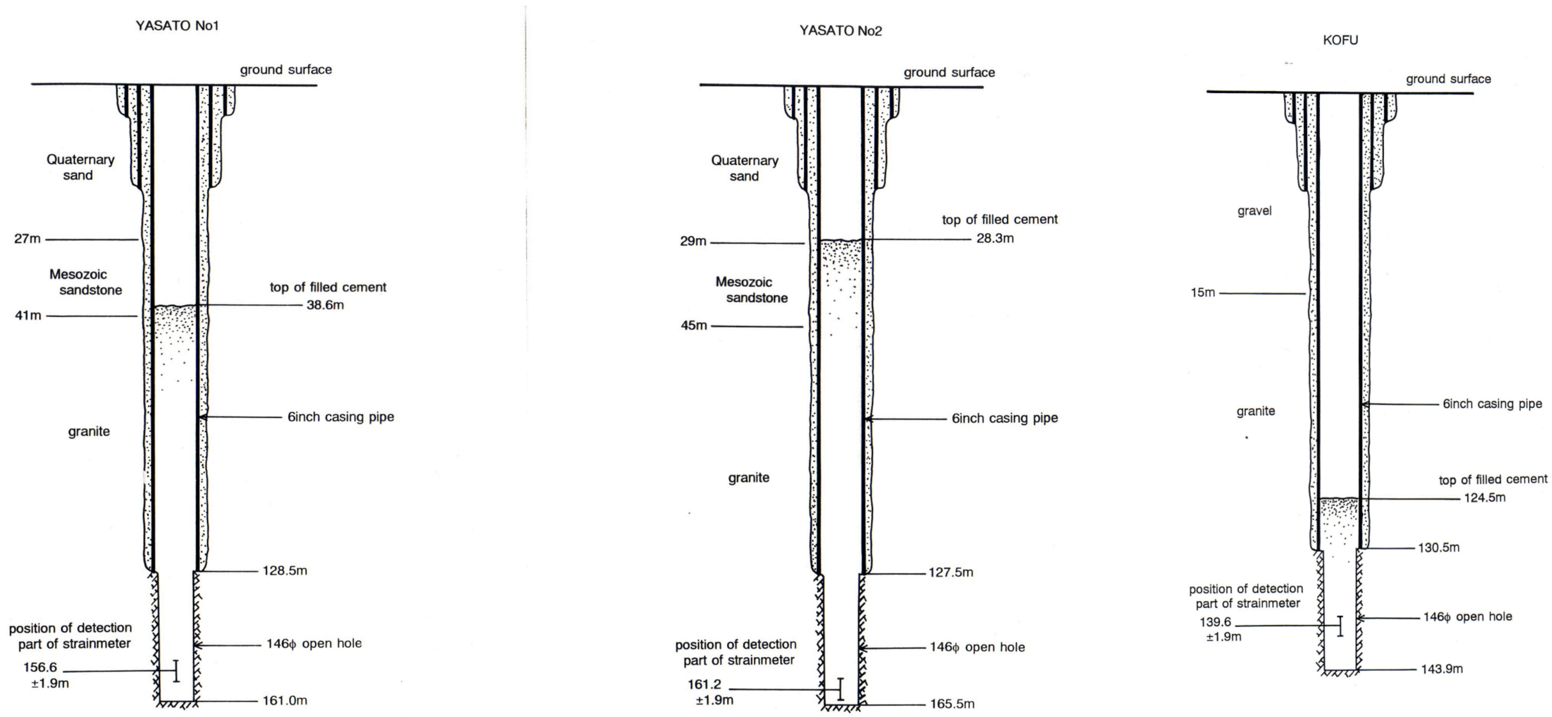
$$\Delta S_1 = A(\sigma_1 + \sigma_2) + B(\sigma_1 - \sigma_2)\cos 2\alpha$$

$$\Delta S_3 = A(\sigma_1 + \sigma_2) + B(\sigma_1 - \sigma_2)\cos 2(\alpha - 120°)$$

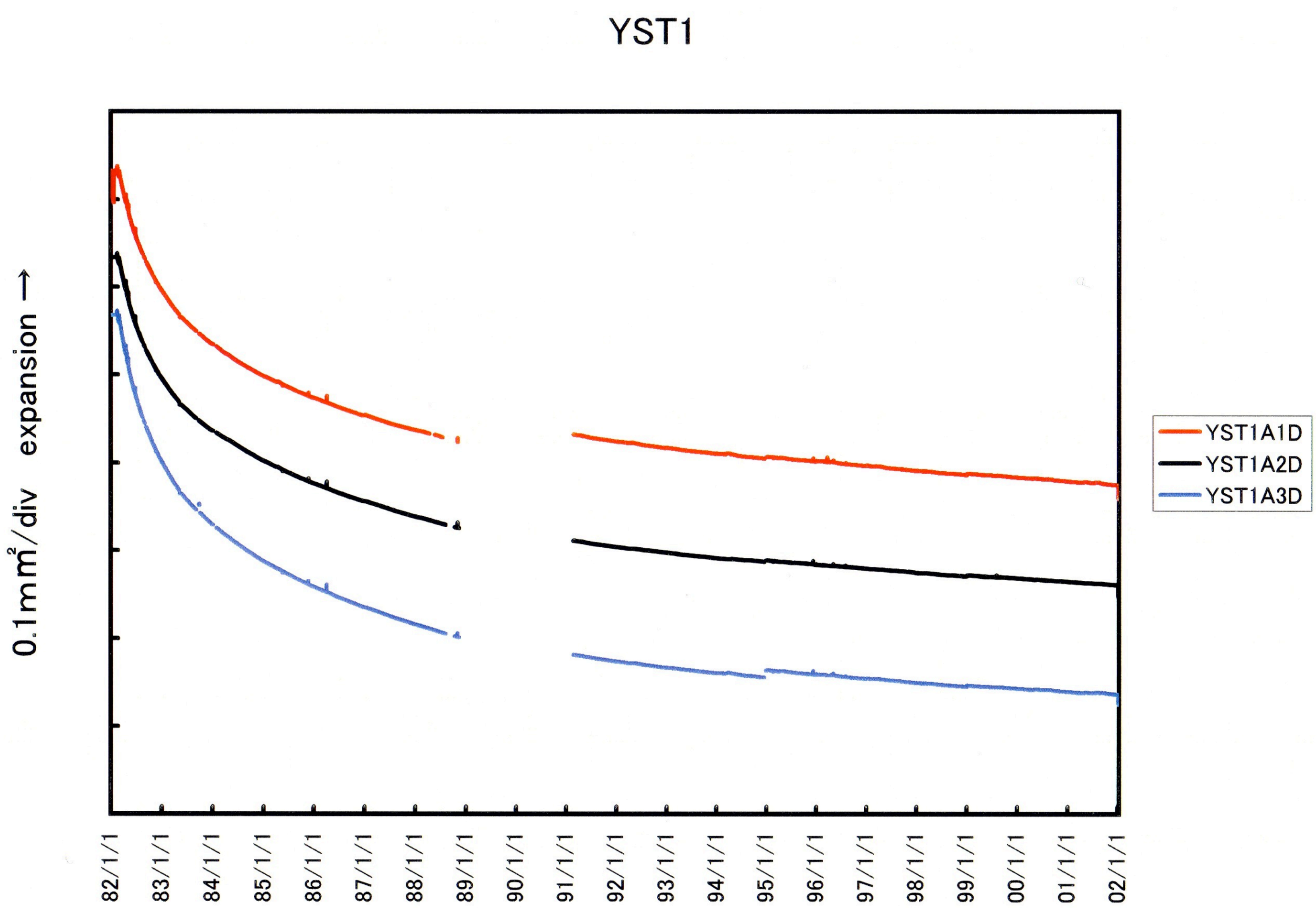
$$\Delta S_2 = A(\sigma_1 + \sigma_2) + B(\sigma_1 - \sigma_2)\cos 2(\alpha + 120°)$$



Location of observation points

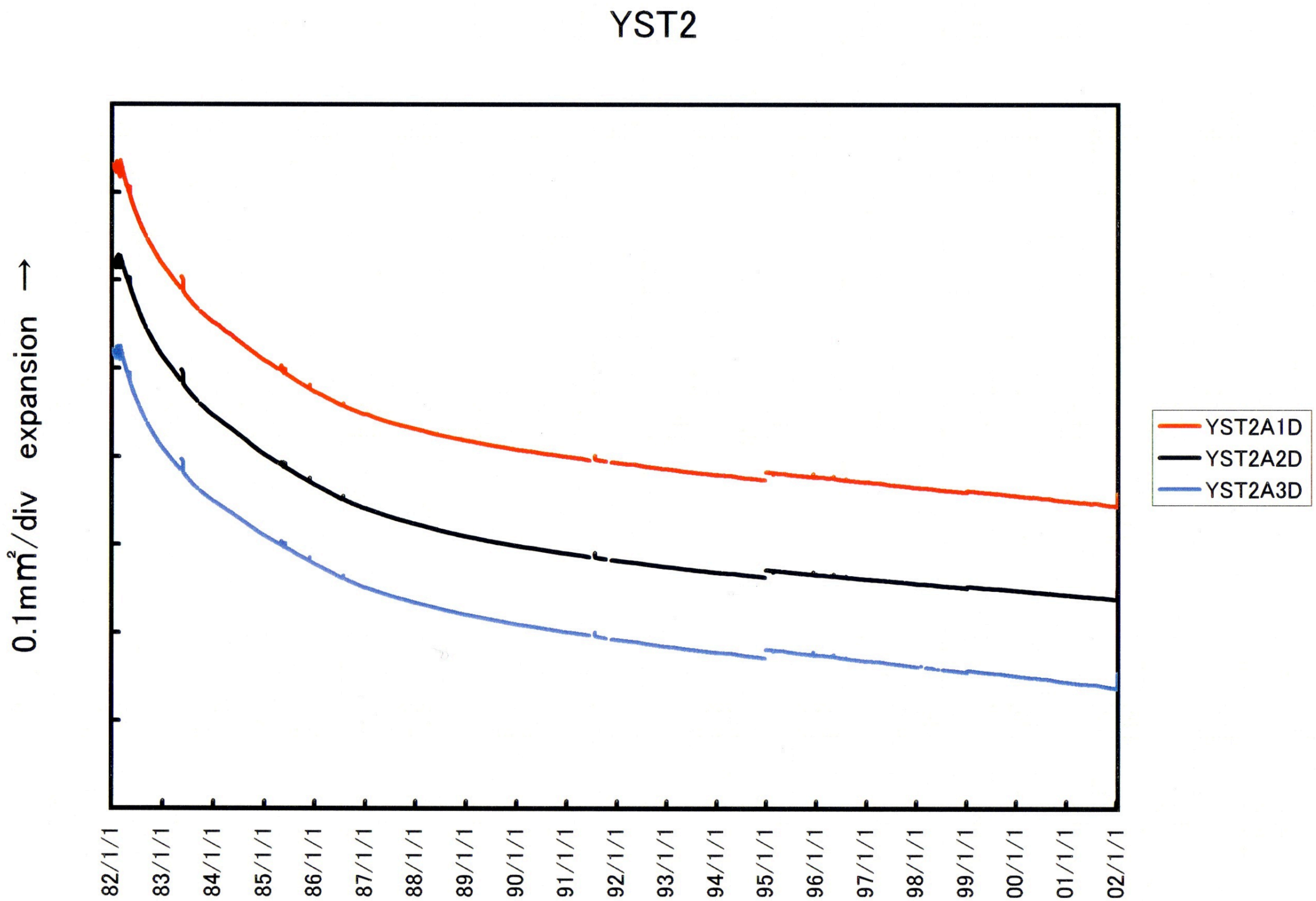


Borehole structures of Yasato No.1, Yasato No.2, and Kofu



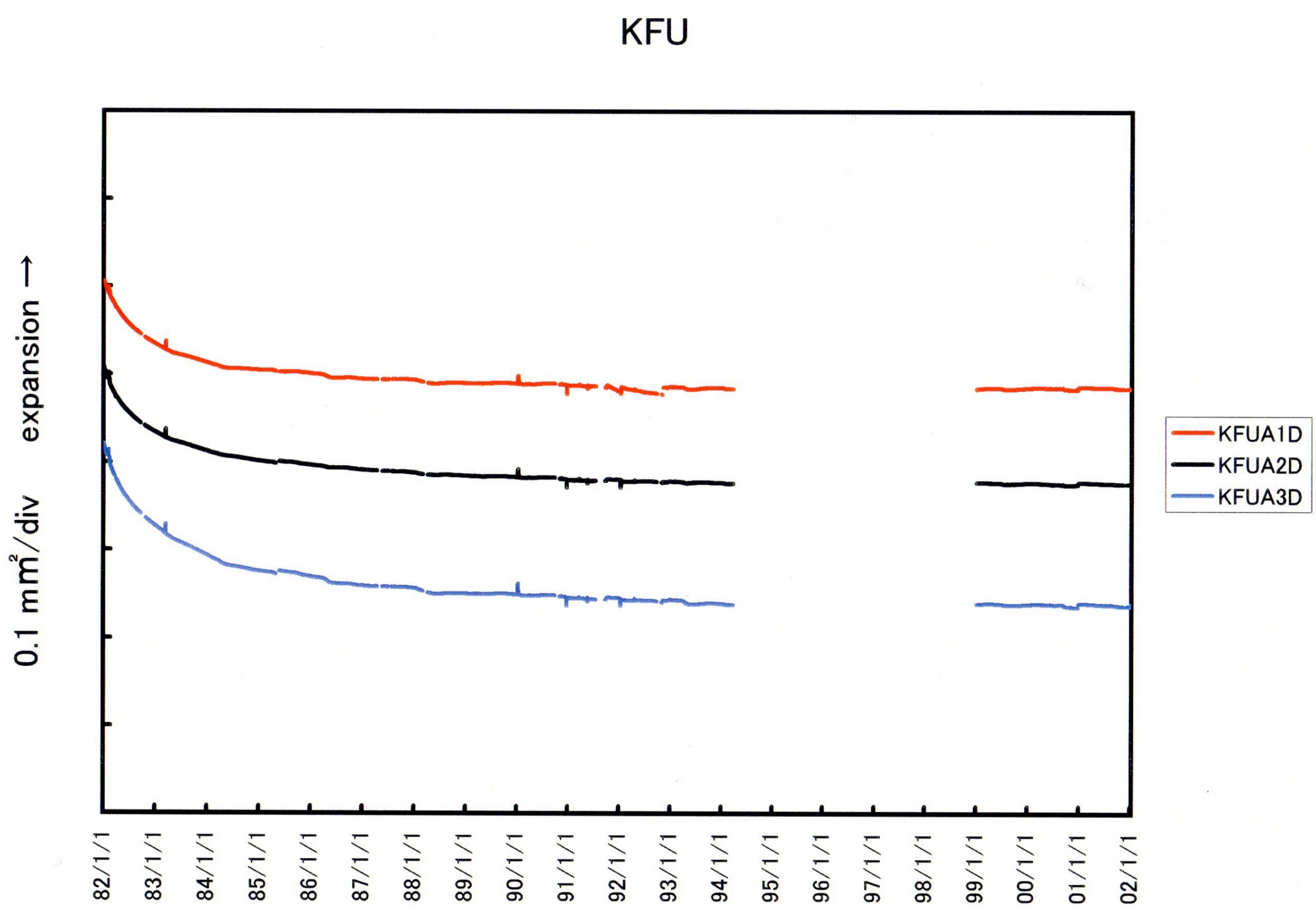
Long-term records of change in three chamber areas

A1D:ΔS_1, A2D:ΔS_2, A3D:ΔS_3



Long-term records of change in three chamber areas

A1D:ΔS_1, A2D:ΔS_2, A3D:ΔS_3



Long-term records of change in three chamber areas

A1D:ΔS_1, A2D:ΔS_2, A3D:ΔS_3

1.Three curves of any instrument have the very similar pattern.

2.This shows that the instrument has been uniformly compressed around the central axis.

3.In the beginning part of any curve, there is a transient part, which decays rapidly with time.

4. In the latter part a steady state term, expressed as $\Delta S_i = C_i - B_i t$, exists.

- **The records suggest that the long-term deformation is due to creep of the surrounding rock to the borehole center as a recovery movement from instability induced by drilling a borehole.**

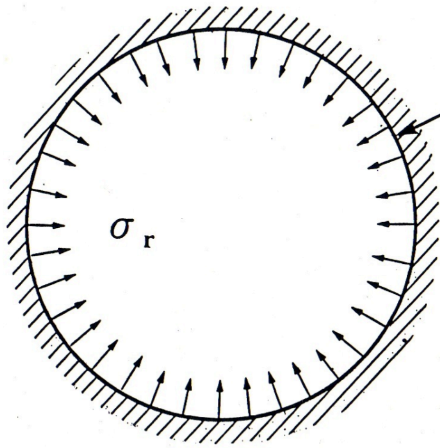
Introduction of equivalent stress

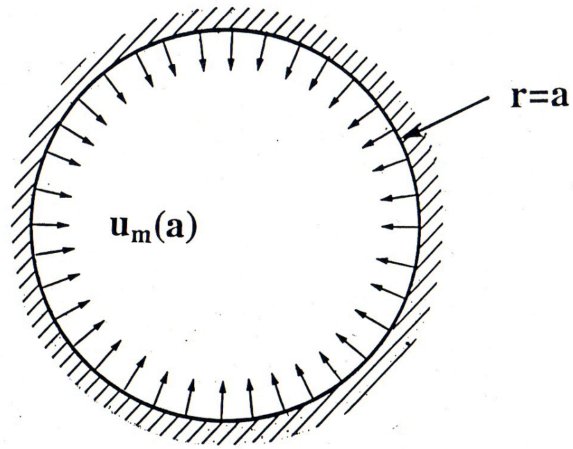
Before drilling : Compressive radial stresses are in a state of stability along the coming borehole wall.

After drilling : Since the inside material was removed, the stability disappears. Equivalent radial stresses can explain the situation.

Deformation of a borehole by equivalent radial stress

Maxwell material (G, η)





$\sigma_r = \rho_m g H$

H : depth of the instrument

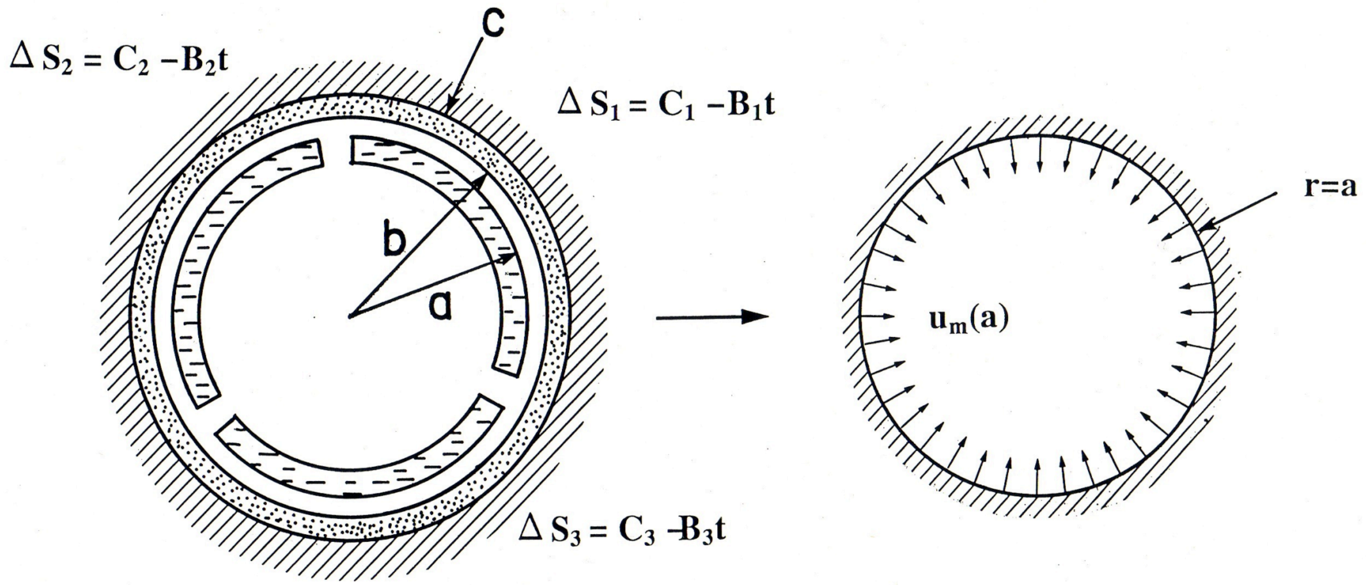
ρ_m : mean density

$u_m(a) = -\sigma_r (1/G + t/\eta) a/2$

$\Delta S = 2\pi a\, u_m(a) = -\sigma_r (1/G + t/\eta) \pi a^2$

☆ **The surrounding rock is supposed to be a Maxwell material.**

Relation between gradients of observed parts linearly changing with time and the deformation of a circular hole in a Maxwell material



$$(\Delta S_1 + \Delta S_2 + \Delta S_3) = \Delta S \times k \qquad \Delta S = 2\pi a\, u_m(a) = -\sigma_r (1/G + t/\eta)\, \pi a^2$$

$$k \fallingdotseq 1/3$$

$$(C_1 + C_2 + C_3) - (B_1 + B_2 + B_3)t = -\sigma_r (1/G + t/\eta)\, \pi a^2 \times k \;\rightarrow\; \underline{\underline{\eta = \sigma_r \pi a^2 k / (B1 + B2 + B3)}}$$

Three partitions serve as obstacles against uniform radial displacement of the inner wall. Constant k shows that effect; the value of 1/3 is based on a rough estimation. u_m (a) is a virtual mean displacement.

Table 1. Elasticity constants and densities of core and mortar samples

	ρ (10^3kg/m^3)	E (GPa)	G (GPa)	ν
Yasato No.1				
core	2.6	40	15	0.33
mortar	2.0	18	6.8	0.35
Yasato No.2				
core	2.6	51	19	0.39
mortar	1.9	20	7.4	0.35
Kofu				
core	2.6	53	21	0.30
mortar	2.1	16	5.9	0.36

Table 2. Viscosities derived from relating stationary creep to characteristics of rocks as Maxwell materials.

	H (m)	ρ m (10^3kg/m^3)	σ r (MPa)	B1+B2+B3 (10^{-16}m^2/s)	η (10^{19}Pa.s)	τ m(= η /G) (100years)
Yasato No.1	156.6	2.4	3.7	4.0	2.8	0.6
Yasato No.2	161.2	2.4	3.8	5.3	2.2	0.4
Kofu	139.6	2.5	3.4	0.74	13	2.2

1.Example of rock viscosities obtained from long-term observation of deflection of rock beams in laboratory (Kumagai and Ito)

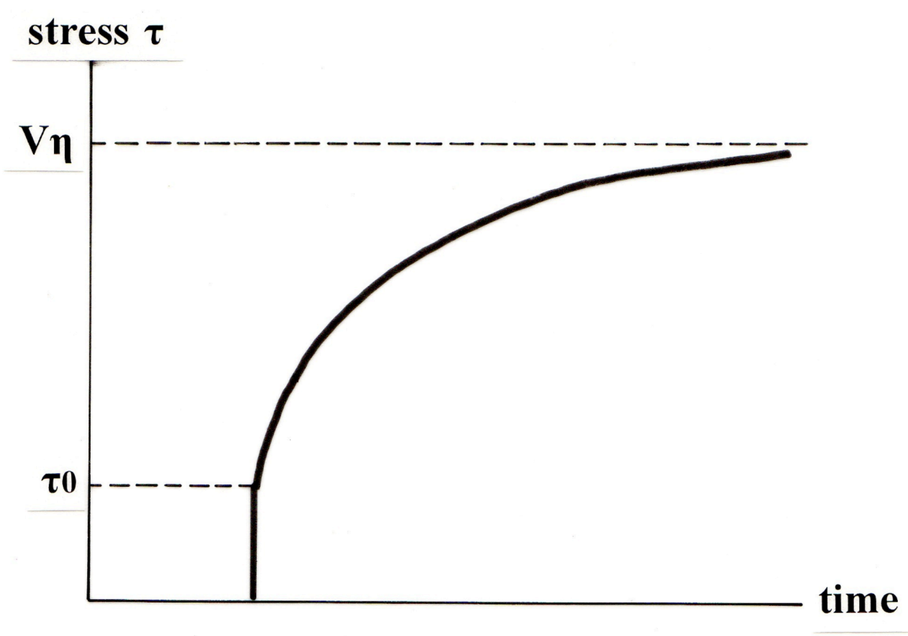
Akasaka granite : (2-5) × 10E19Pa.s

2. Rock viscosities obtained from in situ measurement by borehole strainmeter (Sakata)

Yasato granite : (2-3) × 10E19Pa.s
Kofu granite : 13 × 10E19Pa.s

Where is deformation by tectonic forces?

- In the former discussion deformation by tectonic forces were neglected.
- Deformation by tectonic forces is estimated to be one order smaller than deformation by creep.
- Practically it is difficult to separate the former from the latter.



Behaviors of a Maxwell material
under initial strain and
increasing strain with constant rate

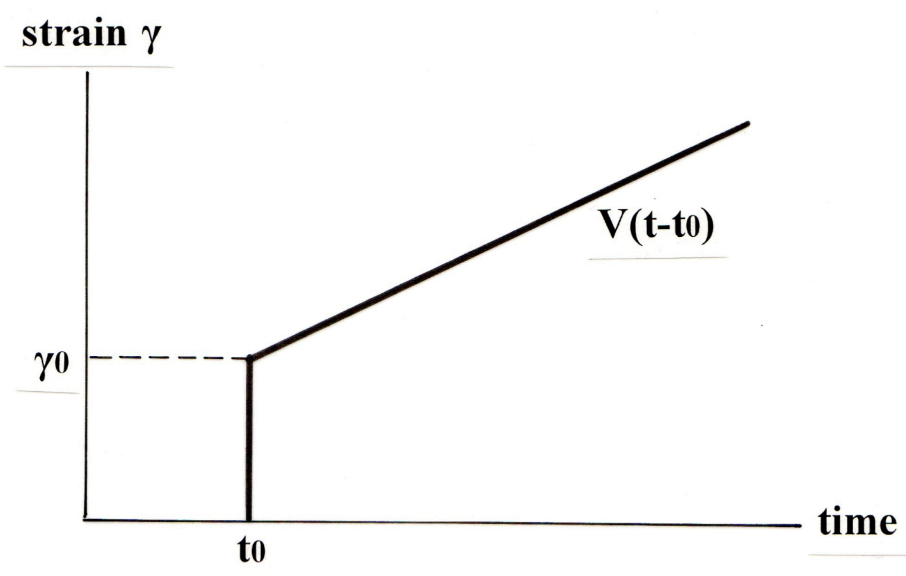
$$\tau(t) = \tau_0 \exp(-t/t_m) + V\eta(1 - \exp(-t/t_m))$$

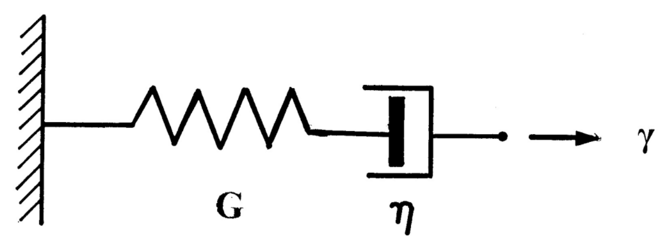
τ_0 : initial stress

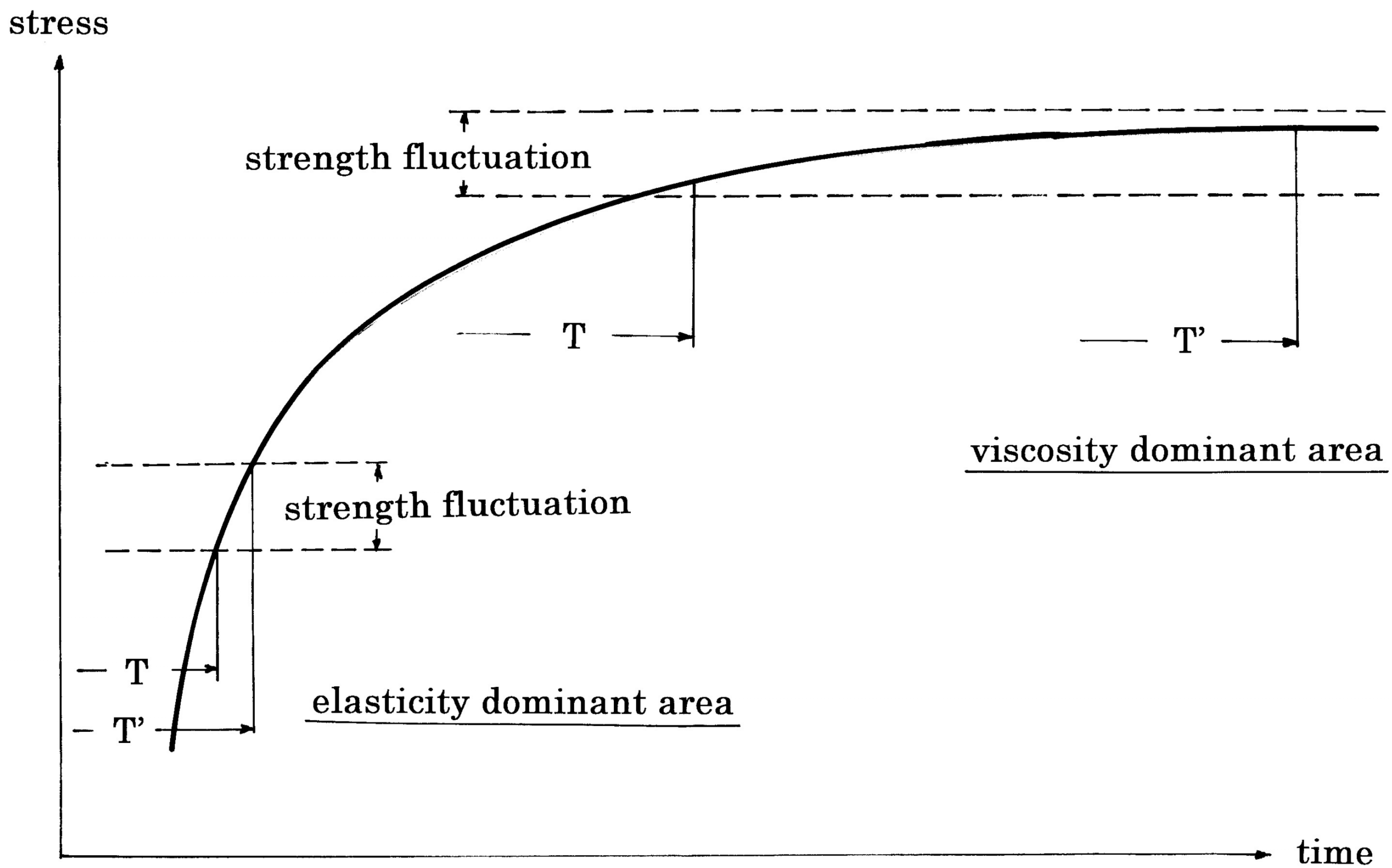
$t_m (= \eta / G)$: Maxwell relaxation time

V : strain rate

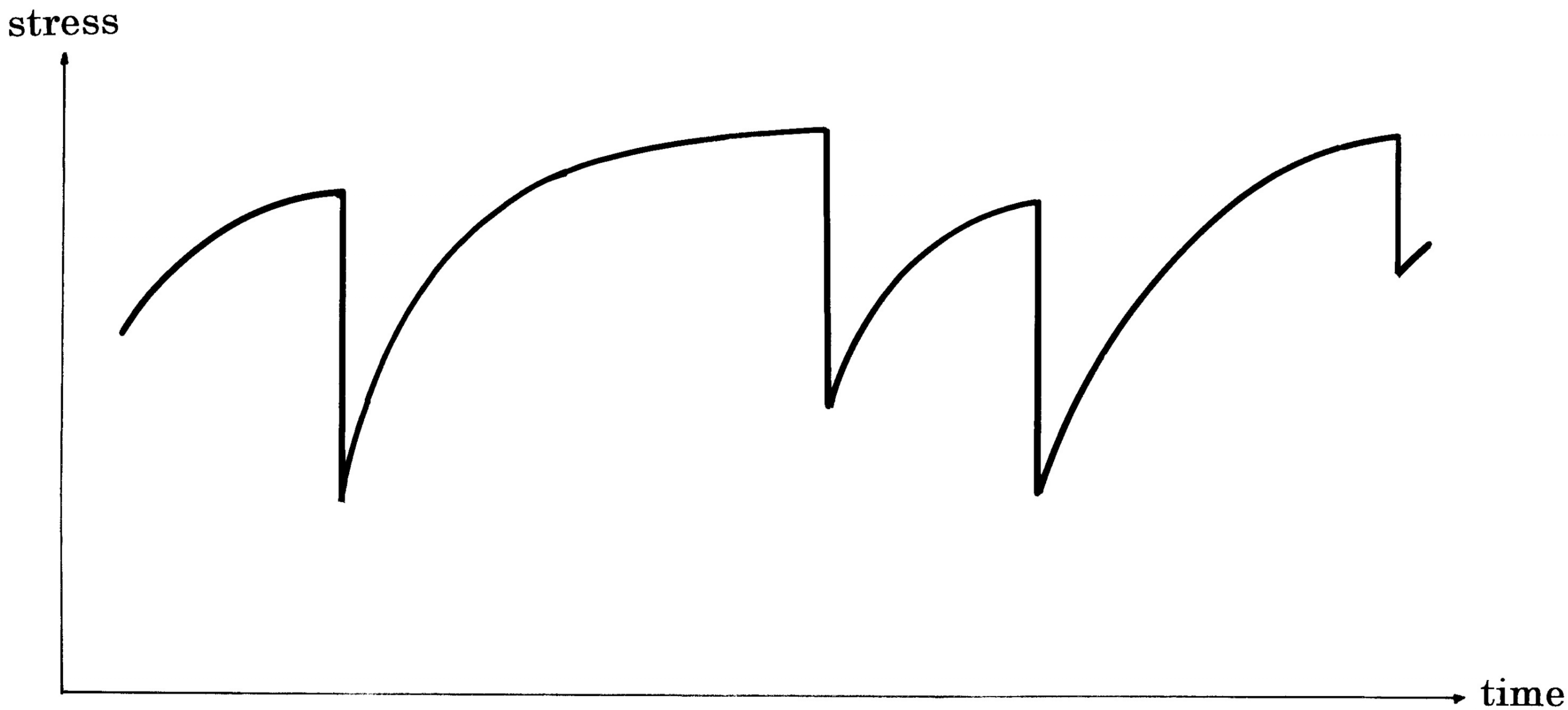
$V\eta$: value of "saturated stress"







A model to explain why recurrence intervals of intraplate earthquakes are irregular compared to those of interplate ones



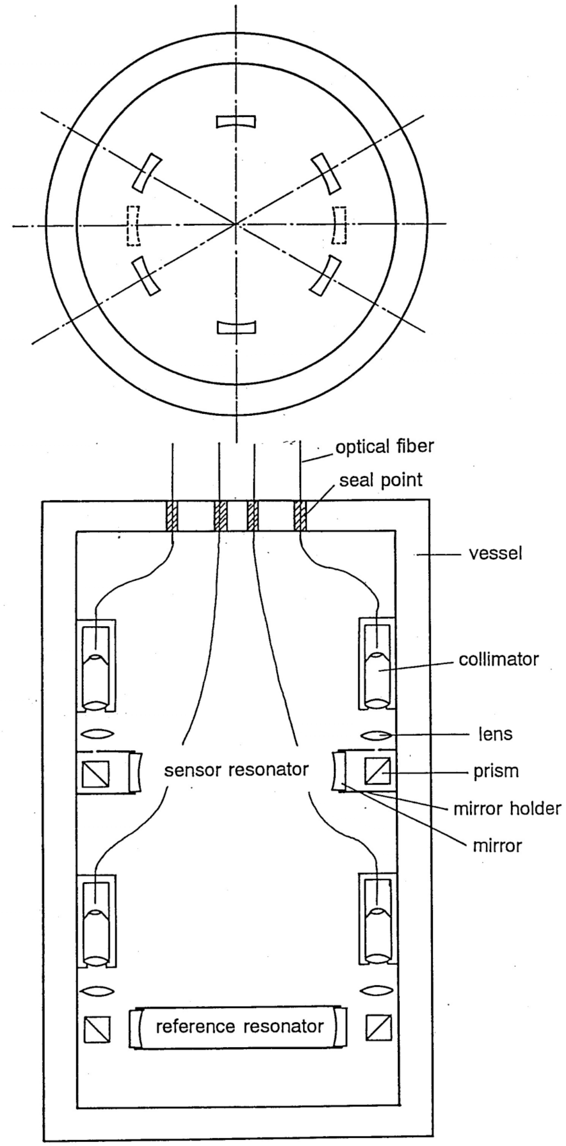
**Speculated stress accumulation curves
with irregular recurrence intervals**

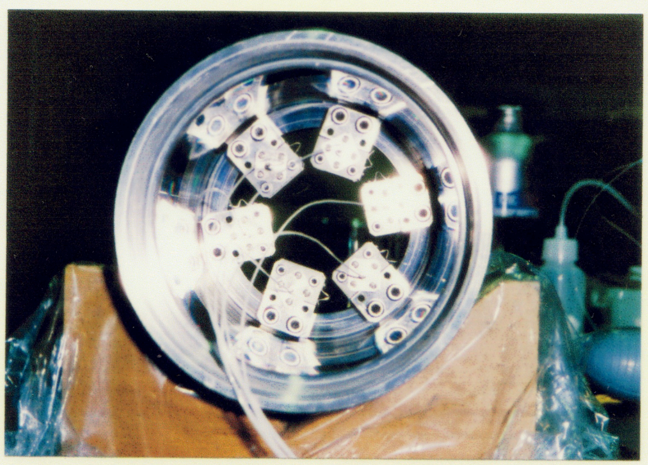
How to obtain viscosities of rocks located in the zone where earthquakes occur.

･We need a borehole strainmeter which can withstand higher temperatures.

･Sakata-Gubin laser strainmeter is under development for that purpose.

Sakata-Gubin type laser strainmeter





Sakata-Gubin type laser strainmeter
above: the land device and
the underground device
below: array of three optical resonators

Last comment

Viscosity measurement in deeper part of the crust will be crucially important for discussion of long-term forecast of earthquakes.